CON

26 September 1958

TO : The Files

FROM: [redacted] 25X1

SUBJ: Communication by Polarization-Modulated Lightbeam

1. Attached is an article by Mueller and Decker which appeared in July 1957 Control Engineering, and which was recognized by [redacted] of the R&D Laboratory as being of interest. This method of communication was discussed at the T. R. Officers Meeting of 9 September 1958. 25X1

2. This report is intended to clarify the capabilities of polarization-modulated lightbeam communication. The following are attributes of this system:

a. Much greater security than with other electrical means, somewhat greater than with ordinary (amplitude-modulated) infrared.

b. Vulnerability to fog, snow, and heavy rain except over extremely short ranges.

c. Strict limitation to line-of-sight transmission paths.

d. Versatility: it is possible to build a transmitter which can utilize many common indoor and outdoor light sources (without electrical connections), rather than a self-contained and self-energized source.

e. Reduced sensitivity to ambient light (remains to be demonstrated).

f. No suspicious twinkling if visible light is used instead of infrared.

g. Possible elimination of setup time required to align the transmitter with the receiver before transmitting (may still be necessary to align the receiver with the transmitting site).

h. Possibilities of transmission (but not necessarily daytime reception) from a moving vehicle.

3. Polarization-modulated systems can be intercepted if their existence is known or suspected: the unusual system of modulation merely adds an additional severe complication to procedures for detecting infrared systems of the standard type. However, if the transmitter package is concealable and can be used with most indoor and outdoor incandescent lights by merely placing the package between the lamp and the receiving site, problems of interception should be multiplied beyond the case of present IR systems, which require skillful and lengthy preliminary adjustments before transmission. It is thought at this time that adjustments at the receiving site will be somewhat more unwieldy than those to the transmitter if daytime operation is contemplated.

4. Pending practical investigation, it is thought that this system is capable of a sufficiently wide information bandwidth to permit, in addition to voice transmission, its use with automatic and semiautomatic high speed keying systems or fast facsimile transmission.

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# Transmitting Data by Light Modulation

Wide-band modulation of light—visible, infrared, or ultraviolet—has been made possible by photoelastic modulation. The advantages to the military are obvious: wireless control or communication without danger of detection or jamming, plus radio silence. Reliable wireless data links open up many possibilities for industrial applications, too. And this one also offers truly private communication. The limitation is the need for a real line-of-sight path. The new technique* permits modulation of very strong light beams, however, so that transmissions over 10 or 20 miles or more are practical.

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Radio communication links have two characteristics that poorly equip them for certain military control problems: they are easily detected by monitoring devices, hence can jeopardize an entire operation; and they can usually be "jammed", as by high-energy noise transmission at the frequencies concerned. Wireless data transmission is very necessary, however, not only for communications between personnel, but also for data telemetering between aircraft and missiles and ground stations. A transmission link that is almost impossible to detect and jam might represent the difference between success and failure for a military mission.

A new method of modulating a beam of light has made possible a transmission technique that is nearly invulnerable to detection or jamming. Of course the use of light as a carrier, rather than radio-frequency electromagnetic waves, definitely limits this technique to line-of-sight distances. But this is usually not a disadvantage for control applications, though it may be for personnel communications.

Earlier methods of light modulation made use of a Kerr cell, in which a dielectric fluid subjected to a strong electric field acts as a light polarizer. Illuminated from one side with polarized light and viewed from the other side through a Polaroid analyzer, the Kerr cell acts as a light valve. The Faraday effect, by which particles in colloidal suspension are caused to line up by a magnetic field, can be used similarly, as can small birefringent crystals. All of these techniques are limited to rather small sizes by the basic nature of the cell or crystal or the difficulties of producing strong electric or magnetic fields over large areas. Practical cells may be only 2 to 3 in. in diameter. These small sizes severely limit the amount of light passed without excessive heating, and thus the maximum range over which the light may be used as a communications carrier.

The new method permits successful modulation of any size light source up to the largest needed for line-of-sight transmission. Essentially, the technique involves the propagation of ultrasonic pressure waves in a transparent plate placed in front of the light source. The pressure waves are induced in the plate by quartz crystals cemented along one edge and driven by an RF amplifier (see Figure 1). The size of the plate and the frequency of the pressure wave

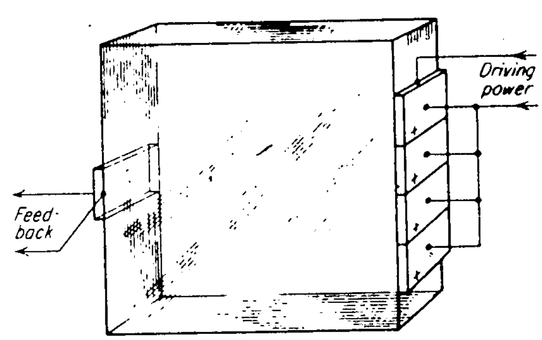


*FIG. 1. Ultrasonic pressure wave is set up in glass block by crystals bonded to (right) edge. Feedback crystal controls frequency of ultrasonic driving source.*

* United States Letters Patent of Robert A. Rines and Hans Mueller, Nos. 2,622,470—2,623,165, and 2,707,749.

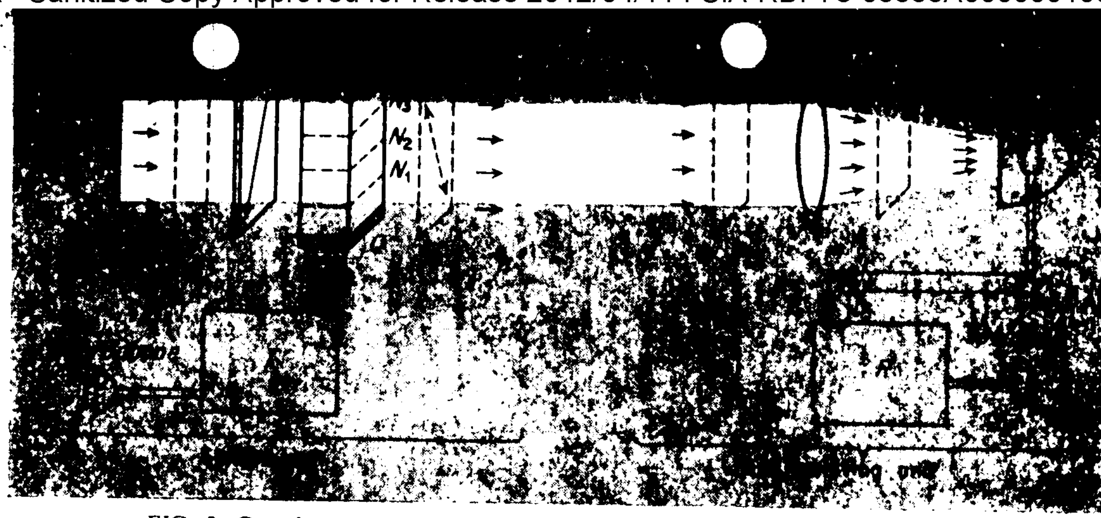


FIG. 2. Complete sending and receiving system. Operation is explained in text.

are such that the plate is many wavelengths long.

## MODULATION TECHNIQUES

The frequency of the ultrasonic source is adjusted to produce a standing pressure wave in the glass plate. This standing wave has nodes of zero pressure between which the pressure varies from maximum tension to maximum compression at the ultrasonic driving frequency. Due to photoelastic effects, tension changes plane-polarized incident light into right elliptically polarized light, and compression changes it to left elliptically polarized light. Therefore, referring to Figure 2, if a light source $S$ is plane-polarized by polarizer $P$ at 45 deg to the nodal lines in the block, and viewed through Polaroid analyzer $A_1$ at minus 45 deg, no light will be transmitted at the nodal lines. The depolarization of the light by the stresses between the nodal lines, however, produces a fraction at minus 45 deg. Since both tension and compression lead to transmission, the intensity of the light reaching the receiver is modulated at twice the frequency of the ultrasonic carrier. This is the first of the four types of modulation illustrated by Figure 3. The nodes (dark) and antinodes are clearly visible when viewed through $A_1$, as in the photograph of Figure 4.

Removing the analyzer from the transmitter and placing it before the photocell of the receiver at $A_2$ produces the modulation shown in Figure 3B. In this case, the light reaching the receiver is an incoherent mixture of right and left elliptically polarized light from the various parts of the area of the block. This incoherent mixture is a depolarization-modulated beam.

To arrive at communication of type C or D in Figure 3, the polaroid $P$ is cut into strips of a width equal to the distance between the ultrasonic nodes. Alternate strips are turned by 90 deg so that they produce plane polarization at plus 45 deg and minus 45 deg to the nodes. In this case, the entire area of the block emits right elliptically polarized light during one half-cycle of the vibration and left elliptically polarized light during the next half-cycle. To transform this into intensity modulation at the carrier frequency, a quarterwave plate must be inserted be-

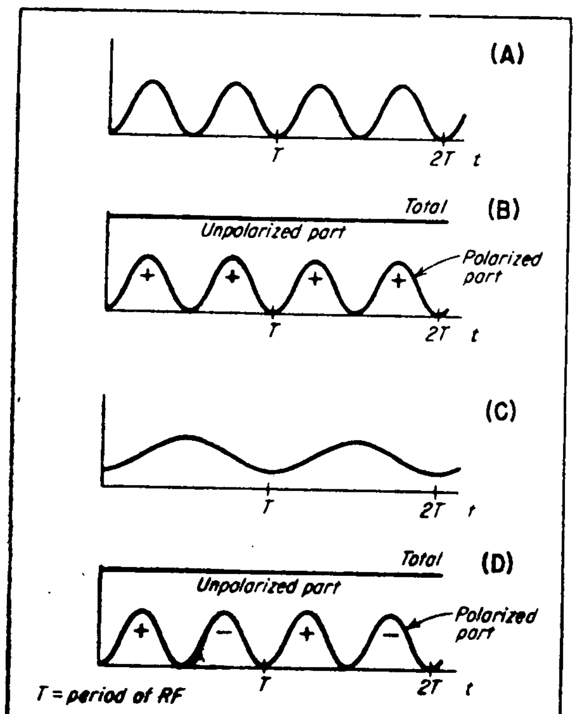


FIG. 3. Types of modulation possible:

A. Intensity or flux modulation at the doubled frequency of the exciting RF carrier.

B. Depolarization modulation at the doubled frequency. This implies that the light reaching the receiver is a mixture of unpolarized and polarized light in which the mixing ratio of the two parts varies periodically with the doubled frequency of the RF carrier.

C. Intensity modulation at the carrier frequency.

D. Coherency modulation with the frequency of the RF carrier. "Coherency modulation" refers to a beam made up of an unpolarized and a polarized part. The total intensity of the beam remains constant and the mixing ratio is modulated. It differs from "depolarization modulation" in that the type of polarization of the polarized part does not remain fixed (e.g., either linear horizontal, or linear vertical, or circular), but changes by switching to its opposite type (from horizontal to vertical linear, or from right-circular to left-circular) after every half-cycle of the RF variation.

tween the block B and $A_1$, so that the combination of the quarterwave plate and $A_1$ form a circular analyzer. Shifting this combination from the sender to the receiver produces transmission of type *D*.

The optical systems of type *C* and *D* provide stronger modulation than those of type *A* and *B*. For identical operating conditions, they double the communication range of the instrument. Type *D* is of special interest because it provides communication which cannot be intercepted or jammed by any known means. The light reaching the receiver is partially circularly polarized, with the polarized part changing periodically from right to left circular. Other light sources or sunlight have no effect on the reception and no other methods are known for creating this type of coherency modulated beams.

In each of the four types of modulation, the amplitude of the ultrasonic carrier modulation can be modulated by audio or control signals. This double modulation is illustrated by Figures 5 and 6.

## Details of the block

Consider a glass plate, 1 to 2 in. thick and, say, 6 in. sq with quartz crystals cemented along one edge, as in Figure 1. For small plate sizes, a single crystal may suffice, but several are generally necessary for plates larger than 3 or so inches. The crystals are cemented to the plate by a special soldering process to obtain as rigid a bond as possible. Because of its natural mode of vibration, each crystal vibrates with largest amplitude at its center, and it has been found that energy is transferred to the plate most efficiently if the polarization of adjacent crystals is the same. To simplify wiring of the X-cut crystals, they are cemented with their optical axes in the same direction, and then simply connected in parallel electrically.

The plate should be good quality glass of low refractive index (1.50-1.55), or fused quartz. Ordinary plate glass is suitable, but crown or borosilicate glass of optical quality is preferable. Fused quartz is suitable only for cw communication because its high mechanical *Q* filters out the sidebands due to modulation. Thickness should be 0.5 in. to 2 in. Transmitting area is unlimited. Blocks with areas from 1 x 1 to 12 x 12 in. have been tested. The blocks of large area permit the modulation of extremely strong light beams. The upper limit is set by heating effects which can be suppressed by air cooling of polarizers and block.

The *Q* of the driving crystals is lowered by the load imposed by the glass plate. This reduces the sharpness of tuning and permits the system to be tuned to an odd multiple of the half-wavelength of the acoustic resonant frequency of the glass plate. This tuning produces an ultrasonic standing wave in the glass, Figure 4.

Referring to Figure 1, the reflecting (left) edge of the plate must be at an antinode to maintain a standing pressure wave. The frequency of the driving source oscillator can therefore be controlled by feedback from a crystal cemented to the reflecting edge and connected in a circuit to sense maximum output.

Because the maintenance of a standing wave requires reflection, the transmitting and reflecting edges of the plate must be ground parallel and polished. There is an interfering mechanism due to the Poisson effect, by which any solid that changes length (elastically) on one axis must also change length (usually oppositely) on another axis in order to preserve the volume-density product (mass). If the plate were exactly square, pressure-standing waves would also appear between the top and bottom edges of the plate due to Poisson vibrations. Since these Poisson waves would interfere with reception of the intelligence present on the original wave, the vertical length of the plate is made slightly shorter (or longer) than the horizontal length.

*FIG. 4. Photograph of Type A modulation looking at light source through analyzer at $A_1$ in Figure 2.*

## Ultrasonic source

The frequency of operation can vary widely for any given size block. For example, for a 6-in.-sq block, there is a standing-wave frequency in every 0.1 megacycle range from 300 kc. to 10 Mc., and any of these can be used. The optimum frequency depends on the ratio of the lengths of the sides, and produces the least cross-modulation. The driving crystal resonance should be chosen close to this frequency. The block in Figure 4 is a 6-in. block, driven at about 0.9 Mc. For transmission of type *C* and *D*, only frequencies below 1 Mc. are practical because of the difficulties in making the polarizers.

Glass blocks require a driving power of only about ¼ watt per cubic inch of glass, so that communications over 10-20 miles and more can be achieved

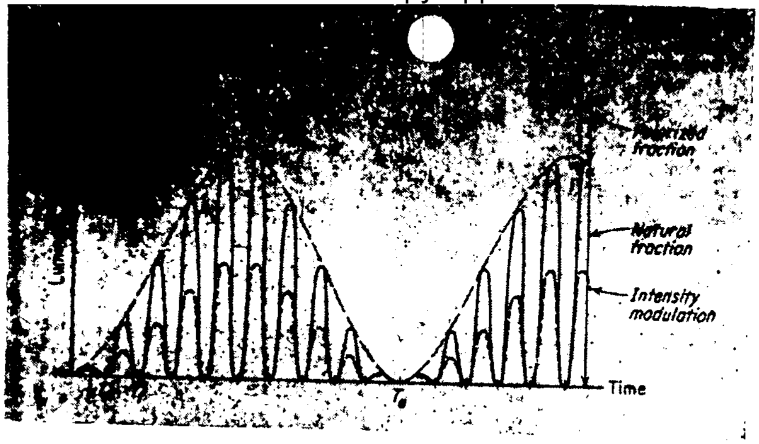


FIG. 5. Amplitude-modulated carrier of Type A. $T_r$ is period of ultrasonic carrier; $T_a$ is period of amplitude modulation.

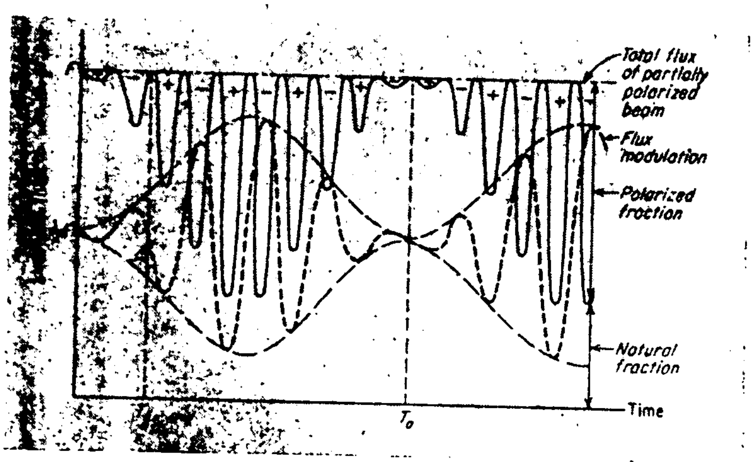


FIG. 6. Coherency modulated carrier of Type D. Note that flux modulation is twice that in Figure 5.

with a 50-watt transmitter and a 6 to 8 in. block. Quartz blocks require only 0.01 watt/cu in.

### The receiver

The receiver is a photoelectric cell. For transmission of types *A* or *B*, the audio signal can be received by using a gas-filled photocell or a resistance photocell, the latter coupled to an audio amplifier or, by means of a photo-multiplier, attached over a tuned circuit to the antenna circuit of an RF receiver. The transmissions of type *C* and *D* can be received only by the latter method. For types *B* and *D* suitable polarizers are inserted before the receiver to transform the depolarization or coherency modulation into flux modulation.

### Light source

The photoelastic modulator can be adapted to any source and for any kind of light (infrared, visible, or ultraviolet) which is transmitted through glass or fused quartz and for which polarizers and quarter-wave plates are available. It can be used for a collimated beam for communication with a single receiver or for beams of large angular aperture. By using a cylindrical block surrounding the source, it can be developed for communication in all directions.

### Test results

Tests so far have used as a source an airplane landing light, and a light filter transmitting the near infrared range of wavelength from 8,500 to 10,000 A. Block areas have been 6 by 6 in. or 8 by 8 in. Block thickness has been 1 or 2 in. The carrier frequency was 0.9 Mc. for type *B* transmission, and 0.35 Mc. for type *D*. Transmission was found to be consistently reliable for 4 miles with type *B*, and up to 7 miles with type *D*. In these tests no attempt was made to focus the beams.

A pilot model for two-way voice communication from ship to shore with the same type of light sources and blocks was successfully tested over distances up to 3 miles in stormy weather (40-mile gale). In these tests, spread lenses created beams with a horizontal aperture of 30 deg and vertical aperture of 30 deg.

## APPLICATIONS

As was said at the beginning of this article, photoelastic light modulation has obvious advantages for the military, where radio silence must be preserved, and where resistance to jamming is needed. The RF source needed to drive the block is easily shielded so that it cannot be detected at distances over 100 ft. Though the light source is easily detected, even if infrared, the modulation is difficult to detect, even if it is suspected. This is because there are two variables, carrier frequency and polarizer angle, and both must be correct at the receiver to detect the modulation. Transmissions of types C and D also require a special polarizer at the receiver which must be changed if the frequency is changed. Jamming is virtually impossible for types C and D.

Industrial and civilian applications include all data-communication problems where line-of-sight contact is normal but wire connections are impractical. Light modulation can be used without FCC restrictions, since it does not use valuable space in the radio bands. At airports it can provide many more non-interfering communications channels (for automatic landing systems, for example) and ground-control channels without using already-jammed radio bands.

The Civil Aeronautics Administration is presently considering a proposal that the rotating beacons on the top and bottom of all aircraft be modulated by this technique. A receiver in each plane would then provide a proximity warning device that could significantly reduce the probability of collisions.

A factory application might be communication with or control of a trolley crane that may move a thousand feet or more down a steel mill bay. Dirt and corrosive environment make trolley wires noisy, resulting in poor communication and erratic control. Several control signals could easily be multiplexed with the voice channel on an infrared light beam.